

The present application is a continuation-in-part of assignee's co-pending U.S. Serial No. 09/271,997, entitled "Multiple Satellite Mobile Communications Method and Apparatus for Hand-Held Terminals," filed on March 18, 1999.

The present invention relates generally to
10 a wireless communication system. More specifically,
the present invention relates to a wireless
communication system with increased frequency re-use
capability for point-to-point communication.

15 Current mobile satellite communication
systems, such as Iridium, Globalstar, and ICO,
utilize low-cost user terminals as one of their key
system features. To maintain communications linkage
with these current mobile systems, the system
20 satellites provide multiple beam and high-gain
services to the subscribers. The low-cost and low-
gain hand-held terminals utilized by the users of
these systems, transmit and receive signals to and
from high performance satellites which populate
25 almost the entire hemisphere. Some of these current
systems require access to at least two satellites to

assure a soft hand-over process as the satellites progress from horizon to horizon. As a result, the satellite system becomes more reliable and available as more satellites come into a user's field of view
5 (FOV). The satellite constellations provided by these current systems are thus sized to guarantee a minimum number of satellites within a user's FOV over large coverage areas at all times.

All of these current mobile satellite
10 communication systems, however, suffer from certain disadvantages. First, they all have limited frequency (the term "frequency" is generalized here to refer to frequency, time slot or CDMA code) resources. Any given frequency over a given ground
15 position can only be utilized by one user at a time. Thus, if one user accesses a satellite using a particular frequency to communicate to his counterpart on the network, other satellites and/or users in the same region cannot reuse the same
20 frequency resource in the same local area. In particular, if a nearby secondary user has a handset that requires the same frequency resource as is being utilized by the first user, the second user is unable to access the system, even via different satellites.
25 This is true regardless of the sophistication of the system, including systems that utilize multiple beam satellite designs. Even when multiple satellites are available at a given geographic location, the same frequency spectrum cannot be used by more than one

limitations on frequency re-use for point-to-point communications.

It is another object of the present invention to provide a wireless communication system
5 that utilizes individual transponders and mobile terminals that are relatively simple and of low complexity.

It is a further object of the present invention to provide a wireless communication system
10 with high system reliability through graceful degradation.

It is still another object of the present invention to provide a wireless communication system wherein the complexity of the system is concentrated
15 at the central processing hub stations.

It is yet another object of the present invention to provide a wireless communication system with more accurate capabilities for satellite and/or user positioning.

20 In accordance with the objects of the present invention, a mobile wireless communication system is provided. The mobile wireless communications system includes a plurality of individual communication transponding platforms. The
25 plurality of individual transponders are each in

user in a local area. The availability of multiple satellites merely serves to increase the availability of the system to the user. However, the total capacity of these mobile communication satellite systems is still limited by their inefficient usage of the available frequency resources. Thus, the potential growth of these current satellite communication systems is inherently limited.

Additionally, current telecommunications systems generally allow only mobile-to-hub and hub-to-mobile communications in most low earth orbit and medium earth orbit mobile satellite constellations. Mobile-to-mobile linkages require multiple hops between hubs. This means that two or more frequency resources must be committed by the system to close the link.

It is clearly desirable to provide a mobile communication satellite system that relaxes the above constraints, and more efficiently utilizes current mobile satellite communication system resources, while also providing much greater opportunity for system growth.

Summary of the Invention

It is an object of the present invention to provide a wireless communication system with reduced

5 The radiated signals are then re-radiated by the plurality of individual transponders and coherently received and processed by a mobile user terminal. The return link signal path is the reverse of the forward link.

15 **Brief Description of the Drawings**

FIGURE 2 is a schematic block diagram illustrating the signal transmission function of a ground telecommunications hub for a wireless communications system in accordance with a preferred embodiment of the present invention;

FIGURE 3 is a schematic illustration of the return link geometry of a wireless communications system in accordance with a preferred embodiment of the present invention;

5 FIGURE 4 is a schematic block diagram illustrating the signal receive function of a ground telecommunications hub for a wireless communications system in accordance with a preferred embodiment of the present invention;

10 FIGURE 5 is a schematic flow diagram illustrating the overall architecture for a multiple transponder wireless communications system in accordance with a preferred embodiment of the present invention; and

15 FIGURE 6 is a schematic illustration of a wireless communication system for point-to-point communication using a variety of different types of transponder nodes in accordance with a preferred embodiment of the present invention.

20 **Best Mode(s) for Carrying Out the Invention**

Referring now to the figures, the disclosed mobile communication system can be utilized to break away from the frequency spectrum limitation discussed above and provide much more efficient means to re-use
25 the allocated mobile satellite and wireless spectrum

multiple times. By eliminating this frequency spectrum limitation on the operation of multiple satellites, the overall capacity of existing mobile satellite and wireless communication systems can more
5 readily expand.

Referring now to Figure 1, a mobile satellite communication system 10 in accordance with a preferred embodiment of the present invention is
10 illustrated. In Figure 1, the mobile satellite communications system 10 is illustrated in a forward link mode. The mobile satellite communications system 10 includes a ground telecommunications hub 12, a satellite constellation 14 comprised of a
15 plurality of individual satellites 16, and a plurality of hand-held user terminals 18 such as mobile phones. As discussed in more detail below, the user terminals 18 can receive signals 20 simultaneously from multiple satellites 16 via broad
20 beam antennas 22. The ground telecommunications hub 12 is in communication with all of the satellites 16 in the satellite constellation 14 individually and simultaneously. The hub 12 also pre-processes user signals to compensate for path differentials before
25 sending radiated signals 24 to the satellites 16, as discussed in more detail below, and similarly post-processes signals received from the satellites.

In accordance with the preferred embodiment, the design of the individual satellites

25 As shown in Figure 2, the processing performed at the ground telecommunications hub 12 is diagrammatically illustrated. The hub 12 tracks, updates, and forward predicts the time variant

[illegible][illegible][illegible]

is shown in a transmit mode in Figure 2. The hub 12 has the capability to address the plurality of satellites 16 individually through the use of antenna spatial discrimination to provide separate signals to
5 different satellites. Alternatively, code identification can also be used to address different satellites independently.

As shown in Figure 2, assuming that there are "H" users, the signals from user 1 to user H,
10 identified generally by reference number 28, are input into the processing center 26. The positions of the various users (1 to H), designated by reference number 30, are determined generally by the circuitry from the various user signals 28. The
15 various user signals 28 for user 1 to user H are then combined for transmission to the different satellites 16, as generally indicated by reference number 32. In this case, the signal is sent to N satellites. The combined signals are then amplified, filtered, up
20 converted, and then further amplified, as generally indicated by reference number 36. These signals are then delivered to a multiple beam antenna 38 where beam-forming processing is done so that the signals can be transmitted to each of the N satellites via
25 radiating signals 24. The beam-forming process can be done in baseband or a low IF frequency band by either digital or analog means. For a low bandwidth (less than a few MHz) signal, digital implementation can provide cost advantages. The processed signal

5 Consequently, the radiated signals from the multiple
satellites will be received coherently by a simple
hand-held terminal 22.

to focus signal strength on the user from multiple satellites 16, which act like sparsely separated portions of a large active reflector. Therefore, the processing on the ground will insert different time delays into the signals 24 which are radiated via various paths (i.e., transponders). The time delays will be inserted into the signals 24 as if the satellites were located on an ellipsoidal surface, of which the two foci are located exactly at the hub 12 and the designated user 18 positions respectively. In low and middle earth orbit constellations, the users 18 and the hub 12 will always be in the near field of the sparse array.

25 same FOV. Figure 3 illustrates the return link geometry for receiving signals sent from the user terminals 18 to the ground telecommunications hub 12. As shown in Figure 3, there are two groups of links

10

20

reference number 48, and then sent to the specific user 1 through H, as generally indicated by reference number 50. It should be understood that both the receive and transmit functions are necessary parts of the pathlink calibration and user positioning.

The technique of the present invention has been demonstrated to significantly reduce the average sidelobe levels. It has been determined that this is due to three factors. First, the proposed architecture is not a periodic array, but rather a randomly spaced sparse array, which has no grating lobes. Although the average sidelobe level at a single frequency is relatively high, the level decreases with increasing bandwidth. Second, the large sparsely filled array formed by the satellites is a large extended aperture. Thus, all of the users on the ground are in the near field of the extended aperture and the wavefronts received by all users are spherical instead of planar. Consequently, dispersion effects become much more pronounced than would be the case in the far field. The dispersion grows very fast as a probe is scanned away from the main beam and the dispersion smears the power distribution very effectively over a finite signal bandwidth. Third, the communication system is preferably designed with a large frequency bandwidth. The information signal will therefore be spread over this bandwidth via CDMA or through short duration waveforms for TDMA schemes.

Figure 5 illustrates diagrammatically the operation of the invention, which allows for the increased re-use of precious frequency spectrum by multiple satellites. The advantages provided by this system include no limitation on frequency re-use by additional satellites for point-to-point communications. Rather, the capacity of this system is only limited by total satellite RF power. Further, the preferred embodiment allows for the use of simple and low cost satellite designs, because the more satellites included in the constellation, the better the performance of the overall system. The system also provides high system reliability through graceful degradation, as well as concentrating complex processing at the hubs.

The preferred embodiment creates demand for a large number of low cost satellites and also uses R2N techniques to perform satellite and user positioning. The more users using this system, the more accurately the satellite and user positions can be determined. However, even more important than the actual positions of the users and satellites are the path lengths traversed by the signals. Therefore, periodic calibration techniques applied directly to those path lengths may be much simpler and more cost effective. The system also benefits from the large percentage bandwidths available with CDMA and TDMA systems.

10

The user terminals 18 receive and transmit signals simultaneously from/to multiple satellites 16 via broad band antennas. The user terminals 18 do not require any capability to separately address the individual satellites 16 in the space segment 54. The hub 12 pre-processes the signals intended for each local user on transmission and post-processes the signals supplied to each local user on reception to compensate for path differentials. These corrections are separately computed and applied to the signals transmitted to or received from each satellite 16 of the space segment 54. While the invention thus far has been discussed in connection with a plurality of satellites 16, it should be understood that a variety of other transponder nodes can be utilized instead of or in combination with one or more of the satellites 16.

5

10

15

20

25

As shown, in the example, the central hub 102 processes signals 116 that are transmitted from the antenna 110 to a high altitude platform 108. In the forward link, the signal 116 is then transmitted from the high altitude platform 108 to the intended user 112, as represented generally by the signal 118. In the return link, the intended user sends a signal 118 to the high altitude platform 108 which then sends a signal 116 to the antenna 110, which is then processed by the central hub 102. Further, the central hub 102 also processes signals 120 that are transmitted by the antenna 110 to a satellite transponder 106. The satellite transponder 106 then transmits the signal 122 to the intended user 112. In the return link, the intended user 112 sends a signal 122 to the satellite transponder 106, which then sends the signal 120 to the antenna 110 for processing by the central hub 102.

Additionally, the central hub 102 sends a signal 114 to the transmitter tower 104, which in turn communicates with the intended user 112 through a signal 124. In the return link, the intended user 112 communicates with the tower 104 through a signal 124, which then communicates with the central hub 102 through line 114 for processing of the signal. While only a single transponder node (i.e., satellite, high altitude platform or tower) of each type is disclosed, a specific system may utilize any combination of such transponder nodes. It should be

understood that any high altitude platform system such as manned/unmanned airships, balloons, or airplanes may be utilized in accordance with the disclosed system. Further, any space-based system
5 that involves one or more spacecraft for point-to-point communications may be utilized in accordance with the disclosed system.

The disclosed exemplary system 100 can greatly improve frequency re-use efficiency for
10 point-to-point communications such as those in multiple telephone and two-way Internet protocol. This improved capability results from the fact that the information for the intended receiver (user) 112 will arrive from all transponders in-phase. By this
15 configuration, information for non-intended users will generally arrive out-of-phase. For non-intended users, the out-of-phase signals will appear as noise. The performance of the proposed invention will depend upon the spatial separations between the various
20 transponder nodes, as well as the remote users. The communication bandwidths between the transponders and the users will also impact the performance. The effect of these on the disclosed system 100 can be determined in a variety of known ways.

25 Thus, the present system 100 can be comprised of a plurality of transponder nodes that are solely part of a pure tower-based system, a system of high altitude platforms, such as a

000000-000000

5 Having now fully described the invention,
it will be apparent to one of ordinary skill in the
art that many changes and modifications can be made
thereto without departing from the spirit or scope of
the invention as set forth herein.